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Radio Continuum Observations of the Quasar-Galaxy Pair 3C 232-NGC 3067

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The quasar-galaxy pair 3C 232-NGC 3067 is well known to show absorption by gas associated with the foreground galaxy against the background quasar (see Stocke *et al.* this volume). Observations by Carilli, van Gorkom, and Stocke (Nature 338, 134, 1989) found that the absorbing gas is located in a long tail of gas which extends from the galaxy toward the quasar and beyond (in projection). Though the HI observations of NGC 3067 indicate that the galaxy has been severely disturbed, there is no obvious candidate in the field which could cause such a disturbance, leading to the conclusion that the system has undergone a recent merger. Our radio continuum observations of this system were designed to study the nature of this highly disturbed galaxy.

We briefly review the VLA HI observations. Figure 1 shows the total HI column density associated with NGC 3067 and the optical field. Figure 2 is a position-velocity plot made along the galaxy axis. Note that the disk of the galaxy has an extended region of flat rotation in the east, with an extent of about 10 kpc and a peak rotation velocity of about 160 km sec^{-1}. In the west, the HI gas extends only to the point where the rotation curve should flatten (about 5 kpc), after which the disk truncates sharply. A cross in figure 1 indicates the position of the kinematic center of the galaxy, which is displaced by about 6" to the west of the optical centroid of the galaxy. Hence, we have strong evidence that this galaxy has been disturbed.

Further evidence that this galaxy has been disturbed is the long tail of HI extending towards and over the quasar. The tail has a length of 24 kpc and a width of 2.3 kpc. An analysis of the velocity dispersion for the emission from the tail shows a steady increase in velocity width from about 30 km sec^{-1} near the galaxy, up to 200 km sec^{-1} at the position of the cloud to the north of the quasar. Prior to our HI observations, this system had been considered one of the prime examples of absorption due to gas in the halo of a foreground galaxy. Our observations demonstrate that this conclusion is incorrect. In fact, our preliminary analysis of the quasar-galaxy pairs studied by Morton *et al.* (Ap.J. 302, 272, 1986) indicates that for every system with known Ca II absorbing gas outside the associated galaxy's optical radius, the galaxy shows evidence that it has been gravitationally disturbed. We conclude that the most likely origin for the low redshift absorption line systems is gas in interacting systems (unless, of course, our line of sight passes through the optical disk of a foreground galaxy), and not galactic halos or extended disks.

We observed this source with the VLA at both 20 and 3.6 cm. In figure 3 we show the 20 cm continuum image at 4" resolution, and the spectral index between 20 and 3.6 cm. In figure 4 we show the 20cm continuum and the HI column density. The quasar has a spectral index of -0.4±0.1 between 20 and 3.6 cm, and appears to be resolved (by about 5% at 3.6cm, 0.7" resolution). NGC 3067 shows knotty continuum emission from the disk at about the 1 mJy level. The spectral index for the emission is -0.7±0.1,

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which implies that the emission is synchrotron radiation from the disk (with minimum energy fields of about 1 to 5 μG, depending on assumptions). Notice the emission both to the north and south of the plane of NGC 3067. This may be emission from the disk seen in projection, or it may indicate high Z emission (distance from the plane of 1.6 kpc).

Crosses mark the position of the optical centroid of the galaxy (to the east), and the galaxy kinematic center (to the west). The highest surface brightness radio continuum emission from NGC 3067 is associated with the kinematic center of the galaxy (which also corresponds to the position of peak HI column density), which may be evidence for an active nucleus. The nucleus must be steep spectrum, since it is not seen at 3.6 cm to a 3σ level of 180 μJy (*i.e.* spectral index $\leq$ -1.2). The continuum emission extends about 3.9 kpc to the east of the kinematic center and 1.9 kpc to the west. Hence, the radio continuum displays a similar morphology as the HI gas: *i.e.* a truncated distribution in the west (albeit on a smaller scale). The truncation of the disk in the west is also evident in the optical line emitting gas, as determined from the long slit optical spectra of Rubin *et. al.* (A.J. 87, 477, 1982). Notice that the radio continuum emission extends in radius only out to where the prominent dust lanes appear.

Our new continuum observations confirm our notion that NGC 3067 is a highly disturbed system, and, in particular, our notion that the western half of the galaxy extends only 1/2 as far in radius as the eastern half. This disturbance must have occured recently, since the galactic rotation would smooth out the observed asymmetry in about 10^8 years. We are left with the problem that there are no obvious candidates which could have caused such a disturbance.

Figure 1: Total HI column density for gas associated with NGC 3067. Crosses mark the galaxy kinematic center (south) and the quasar (north). The lowest contour level is 2.9×10^{20} atoms cm^{-2}, while the peak is 32.4×10^{20} atoms cm^{-2}.

Figure 2: A position-velocity profile along the galaxy major axis.

Figure 3: The 20 cm continuum radio emission (contours) and the spectral index between 3.6 and 20 cm (grey scale). Typical values for the spectral index of the disk of the galaxy are -0.7. Crosses mark the location of the galaxy kinematic center (west) and the optical centroid (east).

Figure 4: The 20 cm continuum (grey scale) and the HI column density (contoured). 3C 232 has been blanked, and is represented by a cross to the north.

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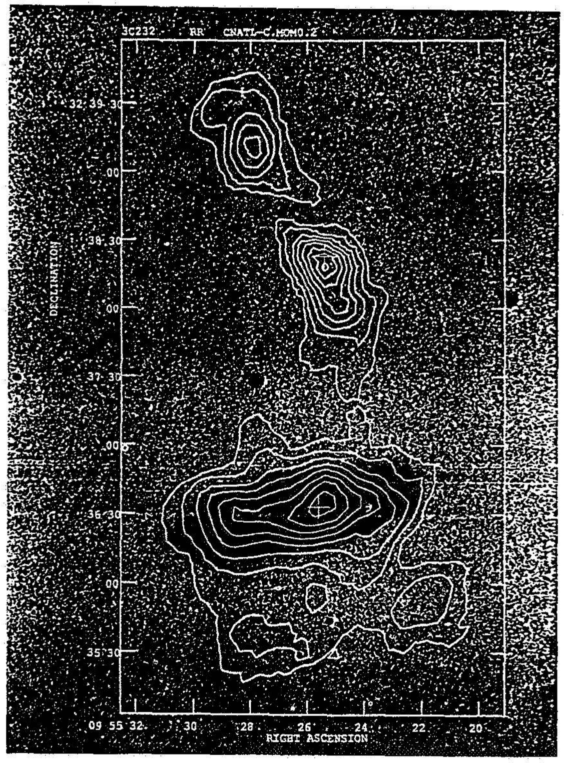

Fig. 1

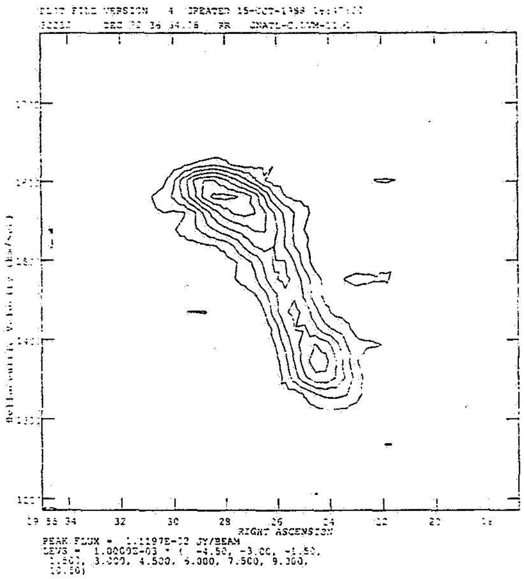

Fig. 2

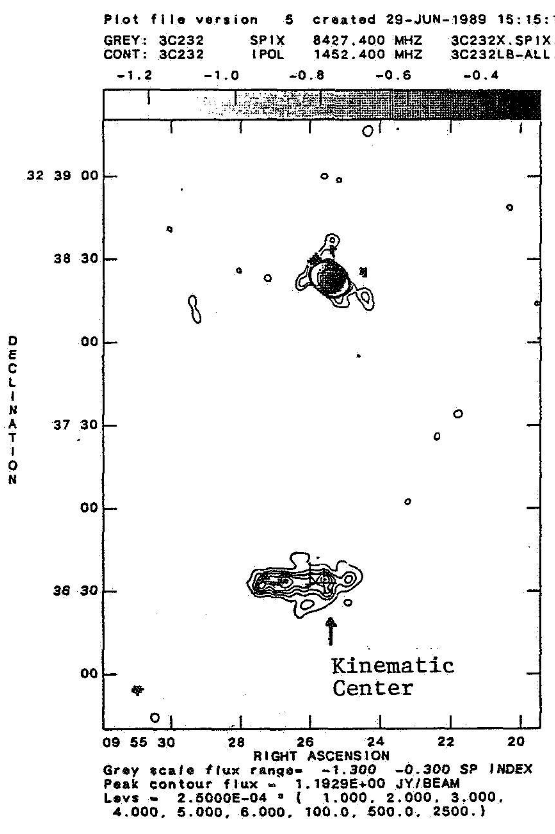

Fig. 3

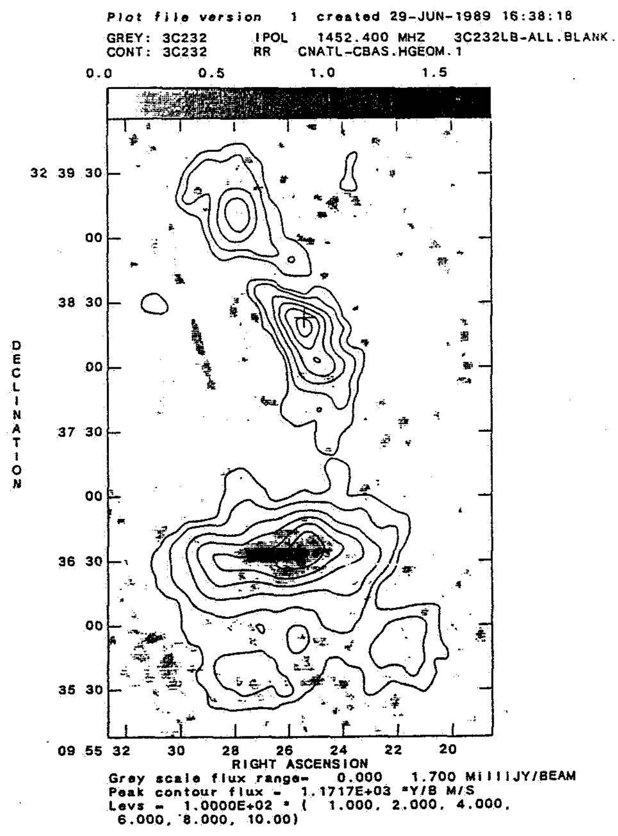

Fig. 4